Strength Testing of Nb_3Sn for Possible New Material of SRF Cavities

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Table of Contents

Abstract

In the Technical Division , our research is based heavily on SRF Cavities. Typically these cavities are made of pure Niobium, however research has shown that a thin coating of Tin on the inner surface of the cavity has improved cryogenic efficiency significantly. To ensure that the Niobium cavities remain in a superconducting state, we cool the cavities to a temperature of 2K with the use of liquid Helium. Since the critical temperature of Nb_3Sn is double that of Niobium at high of 18.3K as compared to 9.2K , it would allow us to remain in a superconducting state at a higher temperature. This would significantly lower operational cost as well as improve the quality factor of SRF cavities. We will research the mechanical properties of Nb_3Sn to ensure the success of the new alternative material of SRF cavities.

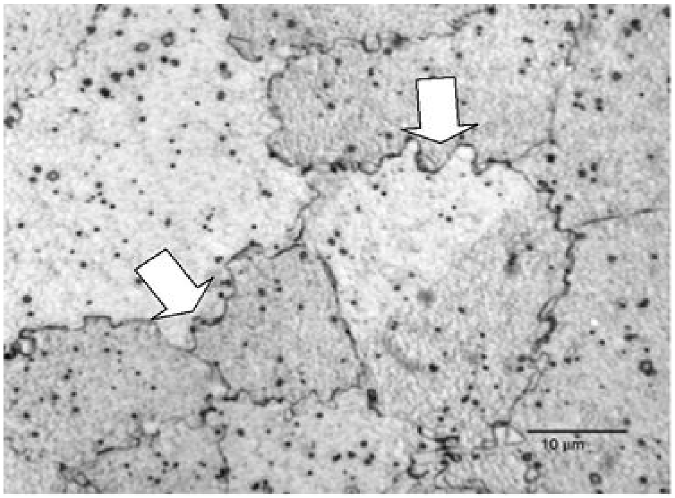
Background

SRF Cavities play an important role in particle accelerators for their ability to accelerate particles at speeds close to the speed of light. Their role in the Large Hadron Collider at CERN in Switzerland has given us much data in the objective of understanding the building blocks of our universe. Superconductors have allowed LHC to accelerate the particles to high energies to bring them to collision inside the 4 detectors of ALICE, ATLAS, CMS and LHCb.

[Figure 1]

As shown in figure one , SRF cavities resemble a dumbbell shape that is made of sheets of 3mm thick sheets of Niobium that are formed by deep drawing half cells and are electron- beam welded together in a vacuum chamber. A post purification process is then done on the Niobium cavity to remove any oxygen from the surface. This is done by placing the Niobium cavity in the furnace with a Titanium rod inside the cavity as well as a Niobium box on the outside with a Titanium layer. The furnace is heated up to a temperature of approximately 1350 degrees celsius for a certain period of time . The purpose of this process is that during heat treatment the Titanium acts as a "magnet " to get attract all the impurities dissolved in the Niobium to its own surface leaving the Niobium at a more pure state. The cavities are then tuned by stretching or squeezing the cavity , so that each cell is relatively the same shape to ensure that the accelerating field is the same for each cell.

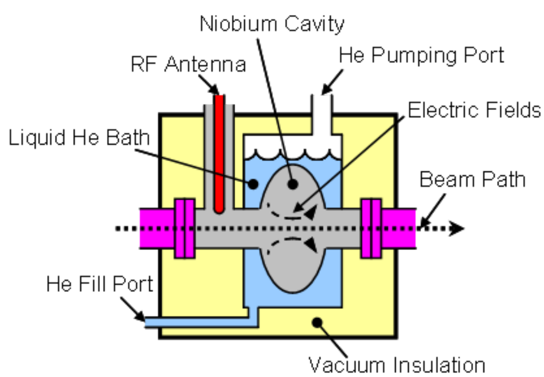
We prepare the surface by chemical treatment that chemically etches away a surface layer on the scale of microns. It removes any damages that occurred on the surface. There is two types of chemical treatments that can be done which include Buffered Chemical Polishing (BCP) and Electro-Polishing (EP). BCP removes the damaged layer by constantly circulating acid over the surface. The acid mixture is made of Hydrofluoric acid , Nitric acid , and Phosphoric acid. The nitric acid reacts with the Niobium to form a Niobium Pentoxide which then reacts with the Hydrofluoric acid to form a hydro soluble Niobium Fluoride which is taken out of the cavity as the acid is circulating. However ,this process limits cavity performance possibly due to the field enhancements of grain boundaries on figure 2 which increases surface resistance. On the contrary , EP removes the material from the metallic surface by immersing the sample in an electrolyte and subjecting it to a current . This removes a small layer ion by ion to get rid of any impurities on the surface. It leaves behind rich shiny surface that protects against future metal fatigue or contamination as seen on figure 3.



(Figure 2)

(Figure 3)

After either of these treatments have been performed , they are rinsed with ultra clean water that is constantly recirculated for several hours to thoroughly remove any chemical and particulate residue from the Niobium surface. The cavity is placed in a dust-free class 10-100 clean room where it is dried and sealed.



(Figure 4)

Once all the steps are completed , SRF cavities are tested and put into use in cryo modules . Niobium cavities remain in a superconducting state when their temperatures remain at 2K using a liquid Helium bath as seen in figure 4 as it is kept in vacuum. A pump is also used to control the temperature in the insulation. The RF antenna provides the cavity with radio waves at resonant frequencies to create a strong alternating electric field in the cavity that accelerates bunches of particles when they are in the same direction.

Introduction

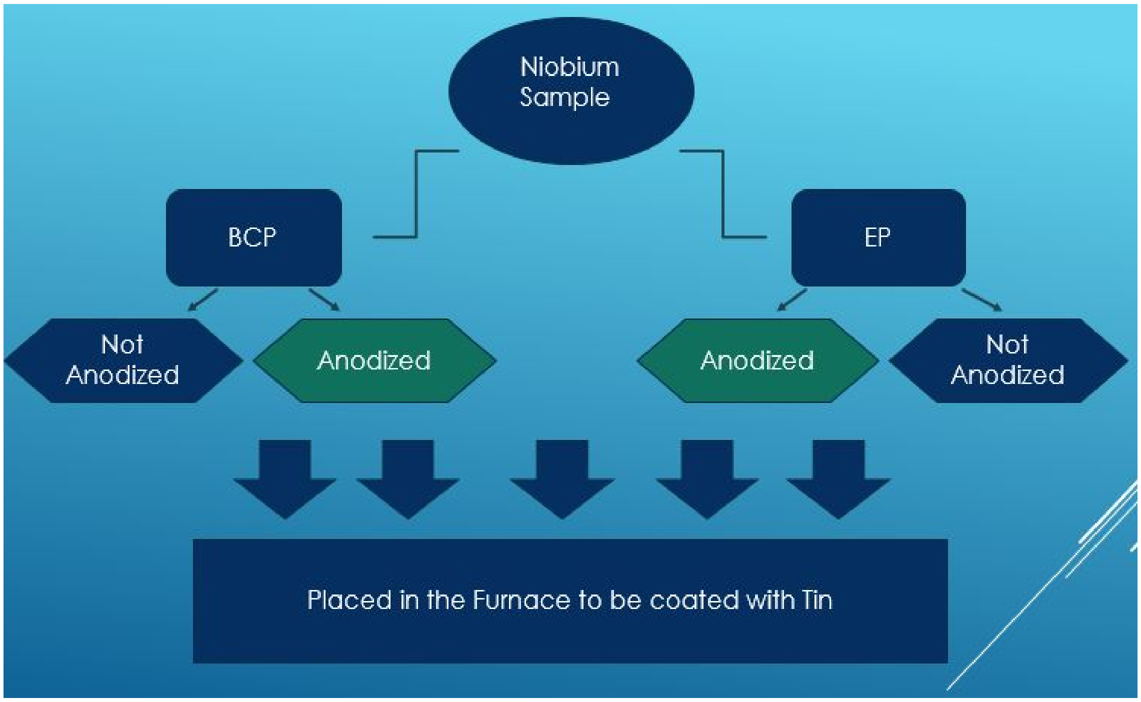
SRF cavities are typically made of pure Niobium however we are currently studying Nb_3Sn as an alternative material for the inner surface of the cavity. The benefits of testing this

Parameter	Nb	Nb_3Sn
Critical Temperature	9.2 K	18.3 K
Operating Temperature	2 K	4.2 K

new material is that as you can clearly see in the table Nb_3Sn has a critical temperature double that of just pure Niobium. We care about this because it means we can operate cavities at a higher temperature of 4.2K lowering down operational cost. This also eliminates the need for a pump because 4.2K is the temperature of liquid Helium at atmospheric pressure which also lowers down operational costs. The Tin coating is done by introducing an Sn vapor at a high temperature of 1100 C to the inner surface of a clean Nb SRF cavity.

The goals of testing Nb_3Sn is to determine whether or not it is a viable material to withstand the manufacturing process of the cavities as well as deciding which type of surface treatment will give us the best quality of Tin coating. We will also test to determine the mechanical strength of Nb_3Sn .

The following flowchart will show the types of treatments that each sample will receive to eventually show the comparisons between different surface treatments to show the best fit of treatment before we coat the samples after the testing methods have been performed.



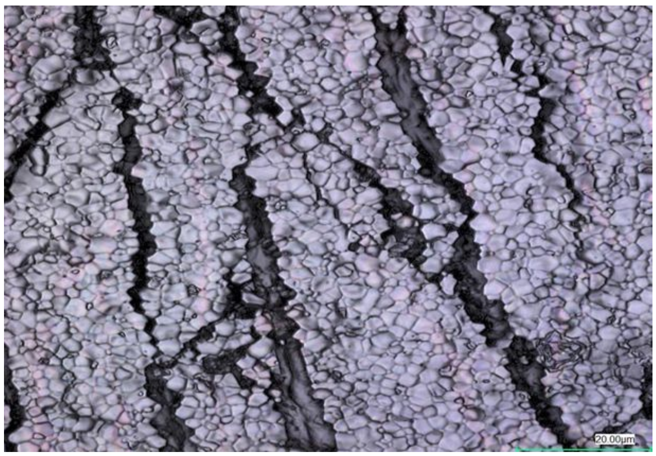
(Figure 5)

We have 4 different courses of treatment before we place the sample into the furnace to be coated. We are focusing on the anodized samples because experimentally it has shown to improve the performance of cavities. When you anodize the metal , It thickens the oxide layer of the metal , which in this case creates Niobium Oxide on the surface .The process is done by passing a direct current through an electrolytic solution , which in this case is ammonia. The niobium metal is serving as the anode releasing hydrogen at the cathode and oxygen at the surface of the Niobium creating a buildup of Niobium oxide.

I will test the different courses of treatments by using the following methods to test for the best one.

Methods

We used a tensile tester (Instron 5967) to place strain on the sample to replicate the strain that is placed on the sample to whether or not the tin coating on the surface would crack under the stress. We will validate this by taking images on the Keyence microscope at 50x and 150x magnification to see the cracks on the surface on the scale of microns. The following image (figure 6) is an example of a sample being strained by 5% .



(figure 6)

You can clearly see the cracks on the surface of material although the metal in the cavity will not experience this level of strain but this shows what we should be looking for when inspecting the images.

In order to complete the tensile tests , we created samples that resemble a dogbone shape in figure 7 that has a gauge length of 25 mm, length of 100 mm , thickness of 3mm , and a width of 6mm. After they were subjected to the surface treatments as well as coating the surface , we took before images of the four different surfaces . I then strained the surfaces the surfaces on intervals of 0.8% strain and after taking images to check for a cracked surface . I strained the sample an additional 1% and took images of the samples at both 50x and 150x to check the surface at a strain rate of 0.01%/s.

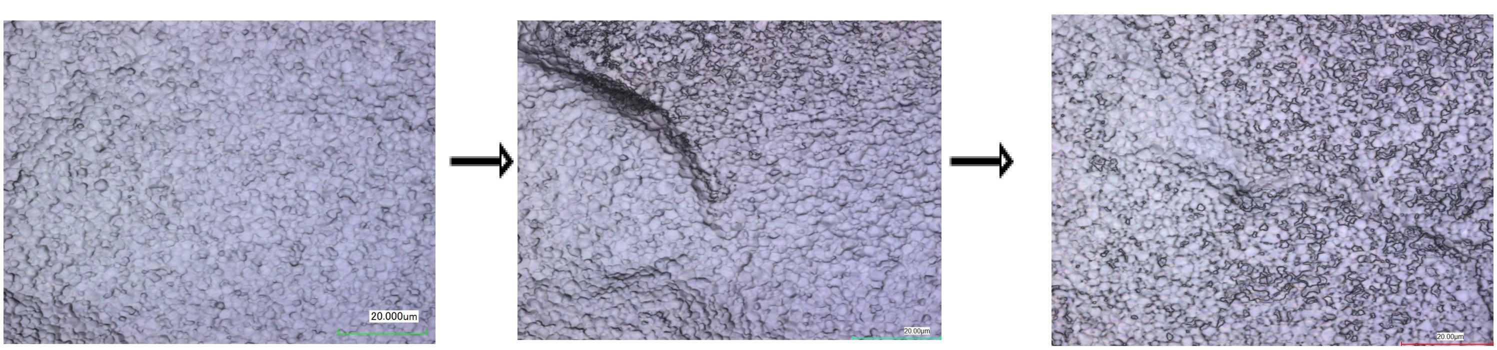
(figure 7)

Results

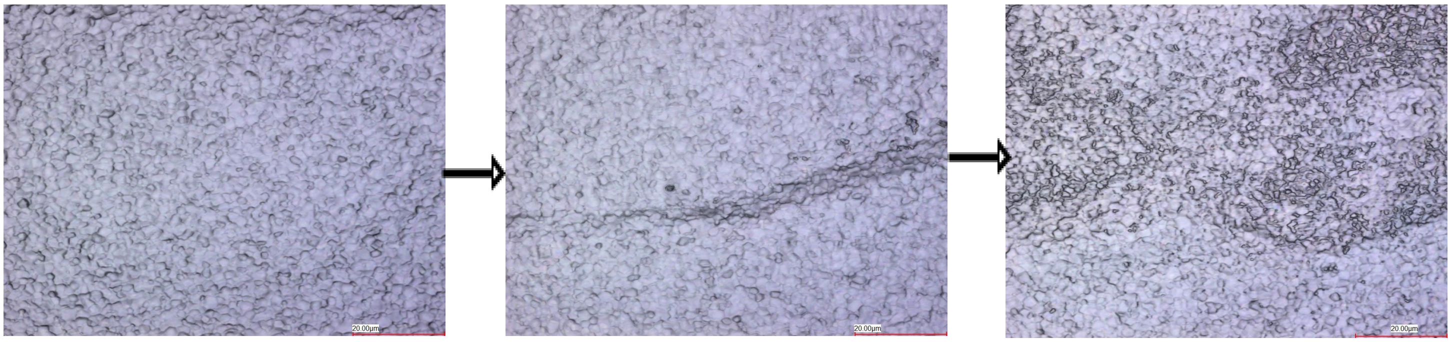
Test samples

Dog bone 5 BCP 65 microns Anodized	Dog bone 6 BCP 65 microns Non-anodized	Dog bone 11 EP 60 microns Anodized	Dog bone 12 EP 60 microns Non-Anodized

Dog bone 5

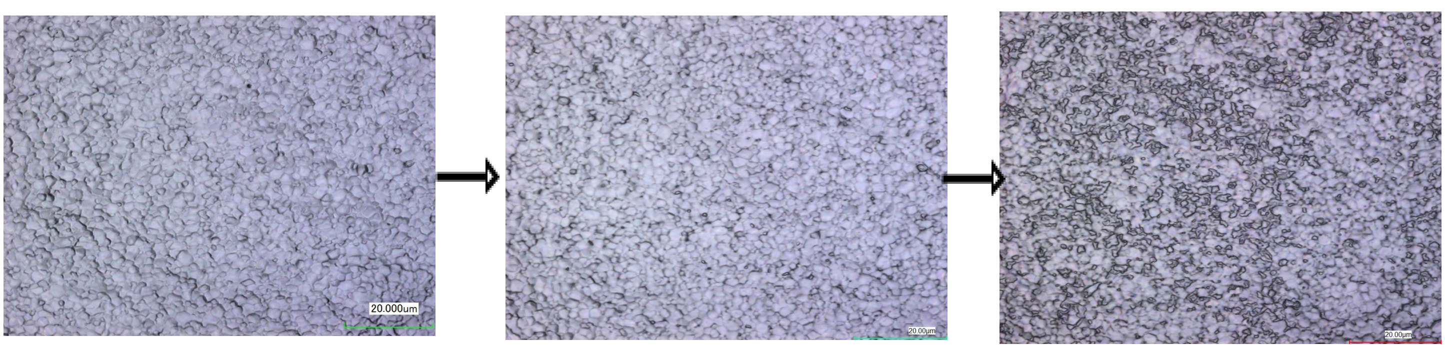


Dog bone 6

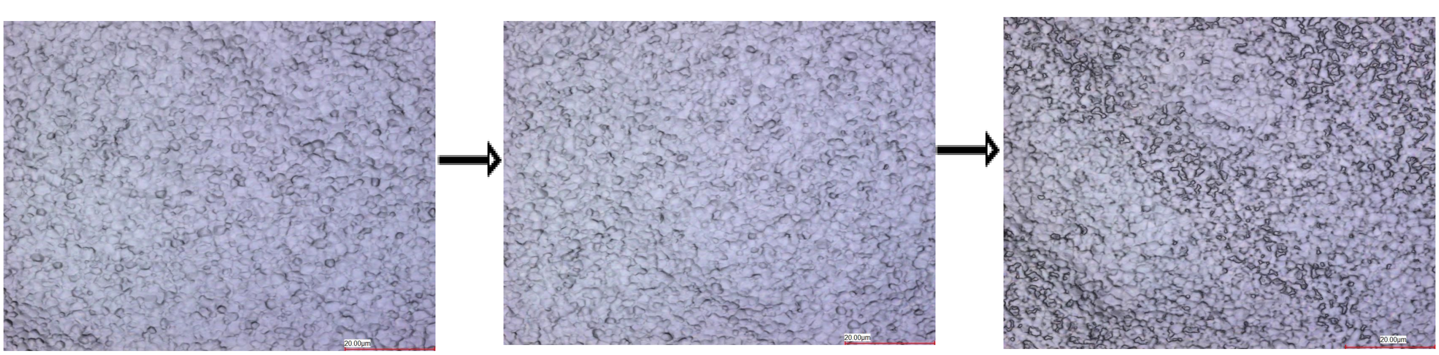


We are comparing the difference between anodized and non-anodized BCP dogbones. Dogbone 6 and 5 present grain boundaries after the 0.8% strain . After the additional 1% strain , the features on the coating increase significantly that might be separation at Nb3Sn grain boundaries. I can not necessarily say that these are cracks until more tests have been performed.

Dog bone 11



Dog bone 12



We are now comparing the difference between anodized and non-anodized EP dogbones. They show less features than that of BCP after just the 0.8% strain , and they show that the surface is a little more smoother. However , they show similar features to that of the BCP samples after the additional 1% strain and again we cannot necessarily say these are cracks yet.

Conclusion

Further investigation is required to verify if those were indeed cracks in the images , and if they are significant enough to affect cavity performance which would need further straining of the samples . If the sample would not crack after an additional 1% strain , we could say that the material would withstand the manufacturing process after we study a bigger sample size to further validate that the material is viable enough to use. For further work , I suggest performing a three point bend test to show a different type of stain to further validate that Nb_3Sn is an excellent candidate for an alternative SRF cavity material.

References

Padamsee, H., Hays, T., & Knobloch, J. (2008). *RF superconductivity for accelerators*. Weinheim: Wiley-VCH.